A METHOD OF PROGNOSTICATION OF THE MOVEMENT OF THE 1000 TO 500-mb THICKNESS PATTERNS

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by

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Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
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ABSTRACT

An accurate prognostication of thickness patterns has long been a crucial problem among forecasters. The importance of such a prognosis can not be over-estimated. It may be used in conjunction with other upper level prognostic charts, and aid in the forecasting of frontal positions and intensities, as well as other important features.

This study investigates the usefulness of the 700-mb winds for advecting the 1000-mb to 500-mb thickness patterns for 12-hour intervals. The resultant prognostic charts are then compared with the actual charts and the percentage errors tabulated.

The sample data is categorized into type of advection, geographic area, location with respect to the major broadscale upper air pattern, and the presence or absence of precipitation. In each category the percentage errors are assessed with regard to the concurrent vertical velocity field at 500-mb as published daily by the Joint Numerical Weather Prediction Unit at Suitland, Maryland. Statistical methods are applied to establish correlations, standard errors of estimate, and, if possible, useful regression equations relating departures from pure advection of thickness to the vertical velocities at 500-mb. The various categories are then compared with the intent of combining those with similar results, in order to reduce the multiplicity of rules.

Finally, the statistical results are converted into empirical rules for adjusting the basic advection. A series of separate charts is used to test the results.

The area included in this study was North America east of the Rocky Mountains; the Pacific Ocean, west to about 150W; and the Atlantic Ocean, east to about 50W. Areas north of 65N, south of 25N and the Rocky Mountain - Plateau Region were not included.

The results definitely established certain degrees of correlation between the rate of advection of thickness lines and the vertical velocity at 500 mbs. Correlation was highest among the cold advection categories under an upper flow from trough to downstream inflection point, ranging from 0.42 to 0.63. For cold advection, inflection to downstream trough, the degree of correlation was considerably less (0.09 to 0.48), due principally to the occurrence of strong polar outbreaks where advection proceeded at a rapid rate in spite of warming contributions by subsidence. This study failed to show any significant difference in the categories over the ocean and those over the land, so that cold advection categories of different geographic location, but with same upper air flow, were combined. However, over the Pacific Ocean the scarcity of data prevented any correlations to be determined. With regard to warm advection, only that type which occurred with clear skies or scattered clouds displayed any degree of correlation, and here it was fairly high (0.68). However, the number of cases in this particular category were rather small. Warm advection with precipitation or with overcast or broken clouds showed no significant correlation. Again, the results with respect to warm advection over the Pacific Ocean were insignificant. Where correlation was significant, linear regressions were fitted to the sample data. In the other categories arithmetic means were computed.

Using the linear regressions and arithmetic means, a table of adjustments was drawn up to be applied to the basic advection by 50% of the 700-mb flow. Since geographic location was not found to be a determining factor, it was not used and each adjustment was considered to apply "everywhere" including the Rocky Mountain and Plateau region.

A week in November 1956 was tested using both the unmodified 50% advection, and the table of adjustments. A consistent improvement was made using the adjustments, even over areas such as the Rocky Mountains where the original research was not conducted. The average score using 50% advection was 0.70. Using the adjustments, the average score was 0.53. The scoring system applied here was the gradient assessment method now in current use at the U. S. Naval Postgraduate School for verifying prognostic charts done by students in the Aerology Curricula.

Both sample data and independent test data was obtained from facsimilie charts prepared by the National Weather Analysis Center, and from the vertical velocity charts computed by the Joint Numerical Weather Prediction Unit. The months of December and January, 1956-57 were used for the sample data, and November 1956 was used for the test data.

This investigation was conducted as the thesis requirement for the degree of Master of Science at the U. S. Naval Postgraduate School during the third and fourth term, January through May, 1957.

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TABLE OF SYMBOLS AND ABBREVIATIONS

h	:	value for the 1000 to 500-mb thickness
R	:	gas constant
p	:	pressure
T	:	temperature
γ	:	lapse rate
W	:	vertical velocity at 500 mbs. (cm/sec)
D	:	relative difference (%)
n	:	number of observations in a sample
$\overline{W}$	:	sample mean of the vertical velocity at 500 mbs. (cm/sec)
$\overline{D}$	:	sample mean of the relative difference (%)
s	:	standard deviation of sample
r	:	sample correlation coefficient
ρ	:	infinite population correlation coefficient
C.L.	:	confidence limits
S	:	standard error of estimate of sample
T	:	displacement along trajectory
N	:	displacement normal to trajectory
w	:	warming relative to 50% advection
c	:	cooling relative to 50% advection

1. Introduction.

The 1000 to 500-mb thickness pattern has for many years been regarded, notably by the British meterologists, as an important primary forecasting tool. This pattern represents the lower half of the atmosphere by weight, and when applied to either the 500-mb or the 1000-mb chart will yield a third dependent chart. Since the thickness pattern represents the mean virtual temperature distribution for the layer, its variations are subject to the same advective, dynamic, and non-adiabatic processes as the temperature pattern.

In addition to its use as an aid for prognosticating the surface pressure field, many other inferences relating to weather phenomena can be drawn from a good thickness forecast. Firstly, concentrations of thickness lines show the locations of significant air-mass contrast, i.e., fronts. Although fronts may exist well to the south of thickness line concentrations in the warm air, they should generally be classified as weak. Secondly, a forecasted crowding or slackening of thickness lines with time, should indicate, respectively, frontogenesis or frontolysis. Thirdly, movement of cold and warm tongues into certain areas should yield indications of stability and convective phenomena. Also, according to Sutcliffe and Forsdyke [1], certain areas in the thermal pattern are favorable for steering, and development of cyclones. Finally, a good thickness prognosis serves as a hydrostatic check for the reasonableness of the combined 1000-mb and 500-mb patterns.

Thus, the forecaster is provided with a valuable complement to other upper air charts. Although upper level prognostic charts such as the 500-mb chart are of considerable accuracy, especially those of the JNWP,

and are available to the forecaster in the field, other prognostic charts such as the surface chart, frontal positions, areas of precipitation, etc., are of lesser accuracy. The local forecaster should concentrate on the preparation of surface prognosis, forecasts of frontal movements and intensifications, and other forecasts to suit the needs of the consumer.

It is the purpose of this investigation to introduce refinements in current methods of forecasting thickness, incorporating available current and prognostic upper air data including the 500-mb vertical velocity field.

2. Development and Initial Procedure.

In order to arrive at an ideal prognosis of the 1000 to 500-mb thickness, advection, adiabatic warming and cooling, and non-adiabatic effects such as radiation, mixing, evaporation, condensation, and precipitation must all be considered quantitatively. Such an undertaking is too extensive for one particular research, and all the necessary information is not available. Therefore, in this paper only the advection, adiabatic, condensation, and precipitation processes will be treated in detail.

The basic equation for rate of change of thickness may be written, [1]:

$$\frac{\partial h}{\partial t} = R\int_{p}^{p_o}\left[-\underline{V}\cdot\underline{\nabla}_h T + \frac{1}{dt}\frac{p}{}\left(\frac{\gamma_d}{g\rho} - \frac{\partial T}{\partial p}\right) + \frac{1}{c_p}\frac{dq}{dt}\right] d\ln p \qquad (1)$$

or may be represented by:

$$\frac{\partial h}{\partial t} = A + D + N \qquad (1a)$$

where A = thickness tendency due to horizontal advection,

D = dynamic thickness tendency,

and N = non-adiabatic processes.

Each of the terms on the right hand side of the above equations will now be discussed separately.

(a). The advective thickness tendency: The advective term may be expressed by,

$$A = -R\int_{p}^{p_o}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) d\ln p = -\left(\bar{u}\frac{\partial}{\partial x} + \bar{v}\frac{\partial}{\partial y}\right) h \qquad (2)$$

where u and v are the horizontal wind components replaced by $\bar{u}$ and $\bar{v}$ which are the horizontal vector mean wind components for the layer.

As an initial step in this investigation, it was necessary to select an appropriate constant pressure level for the advection of thickness values. Since there is no unique level for the vector mean winds to occur, such winds can be obtained only at discrete geographic points by individual hodograph analyses. Such a procedure is impracticable in routine forecasting so that some "best level" must be chosen.

Once such a level is chosen, some method of moving the thickness lines in the given wind field is necessary, as an initial forecasting step, and, in this investigation, to study the other effects causing the movement of thickness lines to depart from that caused by pure advection. It was decided upon to use a method of constructing trajectories known as the Method of Central Tendency [2]. This is a relatively simple method of drawing a prognostic chart based on pure advection of the parameter considered, and it can be accomplished with rapidity and ease not inherent in other more elaborate techniques. It may be described briefly as follows:

A forecast increment of 12-hours is chosen and two constant pressure charts are used for each increment, viz., the current chart and the 12-hour prognosis. In this procedure each chart represents a wind field which is assumed stationary (i.e., trajectories and streamlines coincide) for a period of six hours before and after the verification time of the chart. Values of thickness are moved with the wind along the contours for a six-hour period using the current chart. The values are then picked up by the prognostic chart and moved a second six-hour interval thus completing the forecast interval for 12 hours. Only areas of significant advection are chosen, i.e., where there are numerous intersections of thickness lines with contours. Enough discrete points are then advected with the

wind to show major changes due to advection, and the prognosticated points are then connected by smooth iso-lines of thickness. This procedure can be repeated using successive 12-hour increments.

The main disadvantage of using this technique is based on the assumption of the wind-field remaining static in configuration for 12 hours. This will introduce considerable error in regions of fast moving ridges and troughs of great curvature and in the vicinity of closed circulations. Normally, however, the trajectories will not suffer much distortion except for minor "kinks" showing where the prognostic chart picks up the trajectories initiated by the current chart. These "kinks" can usually be rounded off without introducing error greater than that introduced originally by measuring the wind off the chart. However, this method should not be used for chart intervals of greater than 12 hours.

Regarding the selection of the most appropriate constant pressure level with which to advect the thickness, it would have been convenient in the interests of economy of operation to use either the 1000-mb or the 500-mb level as the representative level. The British, in fact, use the 1000-mb level. Attempts to use 1000-mb winds in this research were unsuccessful because of complications over elevated terrain and surface friction. Also, a vector mean wind with respect to time gives the best wind to advect thickness over a specified time interval, and it was desired to use a level that is most accurately prognosticated. Since the 1000-mb level was to be the final forecasted result, using it as a first step defeats the basic purpose of this investigation. The 500-mb level was tried and proved equally unsuccessful for different reasons. The wind speeds as well as the wind speed gradients were too great, especially under the jets to permit advecting thickness values without

introducing serious magnitudes of error. In addition, intersections of thickness lines with contours were usually at such acute angles so as to introduce great inaccuracies in the construction of the trajectories.

The 700-mb level was finally chosen as the most satisfactory for the determination of trajectories. Although fast moving minor troughs and ridges are more pronounced here than at 500 mbs., trajectories were not too irregular except near closed centers and across sharp troughs. However, the major areas of advection seldom occurred here, but instead well away from centers and to the rear or ahead of the troughs, where contour curvature was more moderate. At the present time 700-mb prognostic charts are not published by the JNWP unit, but with the 3 level baroclinic model, a 700-mb prognosis can be computed [3]. In lieu of a JNWP chart any 12-hour 700-mb prognostic chart may be used.

Since using advection with the total geostrophic winds almost always resulted in an overpredicted pattern, it was decided to use 50% of the wind speed, such as is now in current use. This resulted in a more uniform distribution of error. Geostrophic winds were used except in dense reporting areas, and then observed winds in the vicinity of the value to be advected were selected.

(b). The dynamic thickness tendency:

$$D = R \int_{p}^{p_0} \left(\frac{\partial \alpha}{\partial t} - \frac{\partial T}{\partial p} \right) \frac{\partial p}{\partial t} \, d \ln p \qquad (3)$$

In this term the adiabatic process and vertical advection are both incorporated. $\frac{\partial p}{\partial t}$ represents compression or expansion, being positive in the case of compression (subsidence), and negative for expansion (vertical ascent). The contribution of the terms within the brackets to the dynamic tendency depend on the relative magnitudes of

each term. The first term represents the dry adiabatic lapse rate and the second term represents the lapse rate of the environment, both adapted to constant pressure coordinates. Thus, with subsidence, the tendency is positive, and the values of thickness tend to increase over a fixed geographic point. Ascent, on the other hand, will produce a negative tendency only if the environmental lapse rate is less than the dry adiabatic lapse rate, or, if the air is saturated, less than the saturation adiabatic lapse rate.

Synoptic experience, as well as the statistical results described subsequently, bears this out. Thickness patterns are often markedly distorted by subsidence, and especially, the process of cold advection in lowering thickness values at a particular station is frequently nullified at least in part by subsidence. Ascent, however, has a less decided effect on the thickness patterns. Adiabatic cooling and the process of condensation with release of latent heat to the air work in opposition. Only in cases of forced ascent of a stable dry air mass will there be a net cooling effect on the thickness values. The same will apply to forced ascents of stable moist air in large precipitation areas such as are found ahead of warm fronts and near centers of cyclones.

The processes mentioned above are directly related to vertical velocities in the atmosphere. Petterssen [4] derives an equation similar to (3), but for a single constant level surface.

$$\frac{\partial T}{\partial t} = -v_z(\gamma_d - \gamma) \qquad (4)$$

where v_z represents the vertical velocity in constant level coordinates. The JNWP unit computes and publishes daily the vertical velocity field, both current and prognostic, at 500 mbs. Since this should indicate the

areas of subsidence and ascent in the 1000 to 500-mb layer, the next step of the investigation would therefore follow. This was the correlation of errors in the prognostic thickness pattern using a fixed 50% advection with the sign and magnitude of the 500-mb vertical velocity. As a preliminary procedure, to establish qualitative relationships, "difference charts" depicting the departure of actual thickness from thickness prognosticated by using 50% advection alone were drawn by subtracting, graphically, the actual pattern from the prognostic pattern. The resultant areas of positive and negative errors were then compared, by inspection, with areas of ascent and subsidence indicated on the vertical velocity charts, (Figs. 1a., and 1b.). There is considerable agreement in these particular examples between areas of negative error, (i.e., too much cooling) and subsidence, and between areas of positive error and ascent. Thus the effect of subsidence and ascent in modifying the thickness pattern is shown to be, at least, generally significant.

However, these procedures do not lend themselves directly to statistical evaluation, nor to the formulation of forecasting rules. The statistical procedures actually used in this research will be described shortly.

(c). Non-adiabatic processes: These cover numerous processes such as radiation, mixing, etc. Except in a brief qualitative fashion, these processes were not treated in this paper.

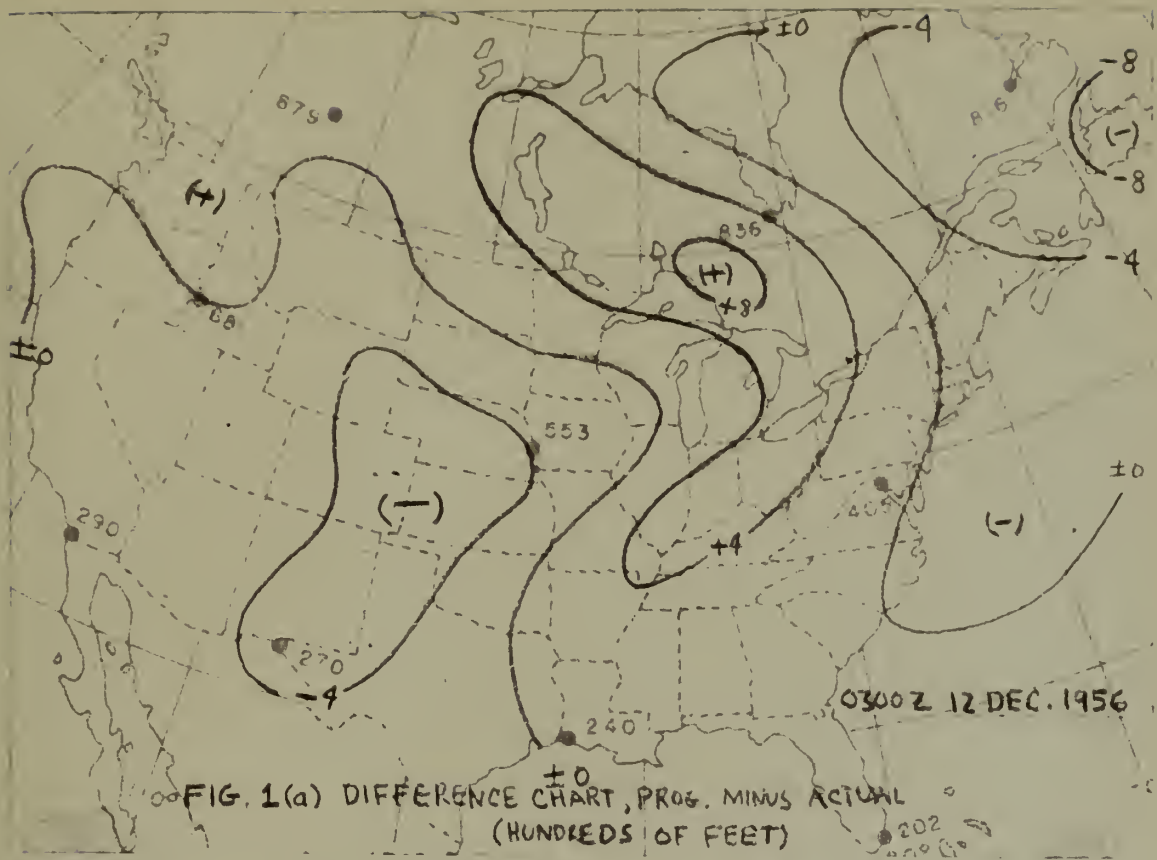


FIG. 1(a) DIFFERENCE CHART, PROG. MINUS ACTUAL (HUNDREDS OF FEET)

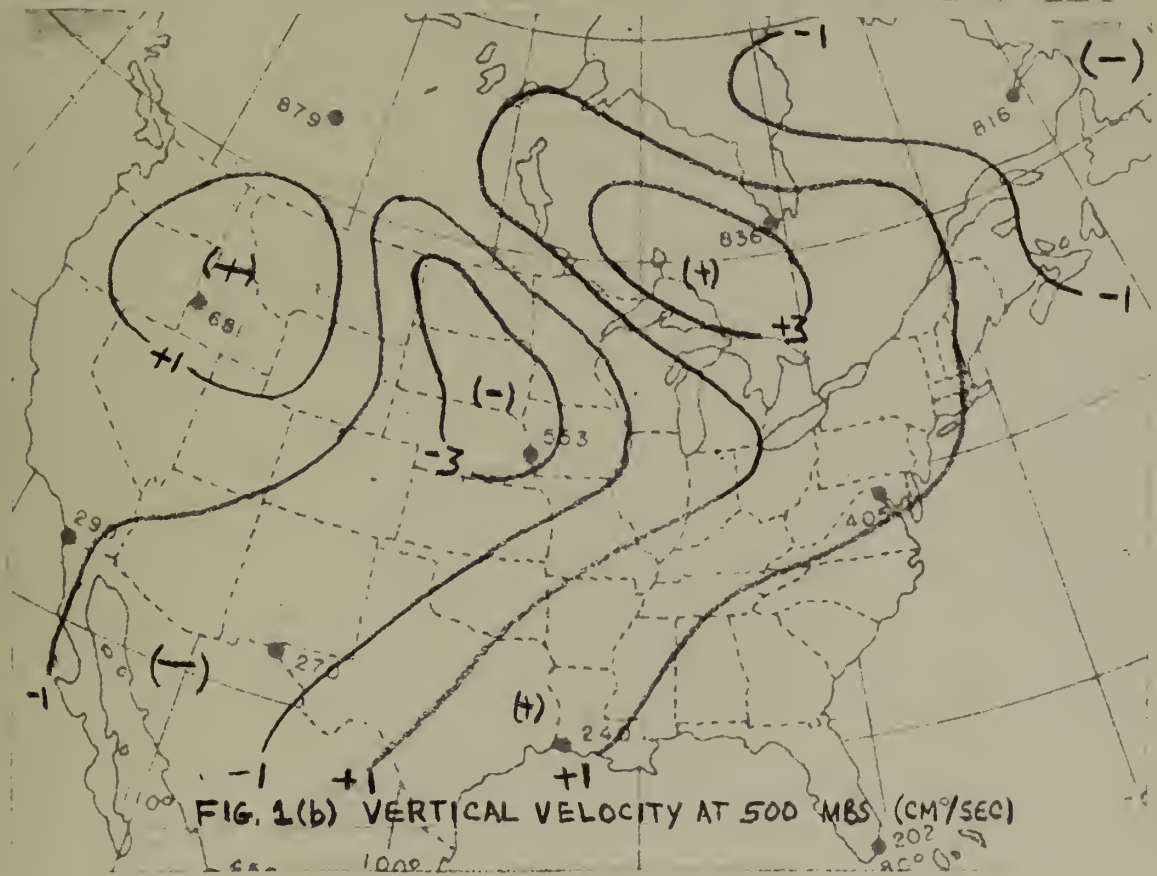
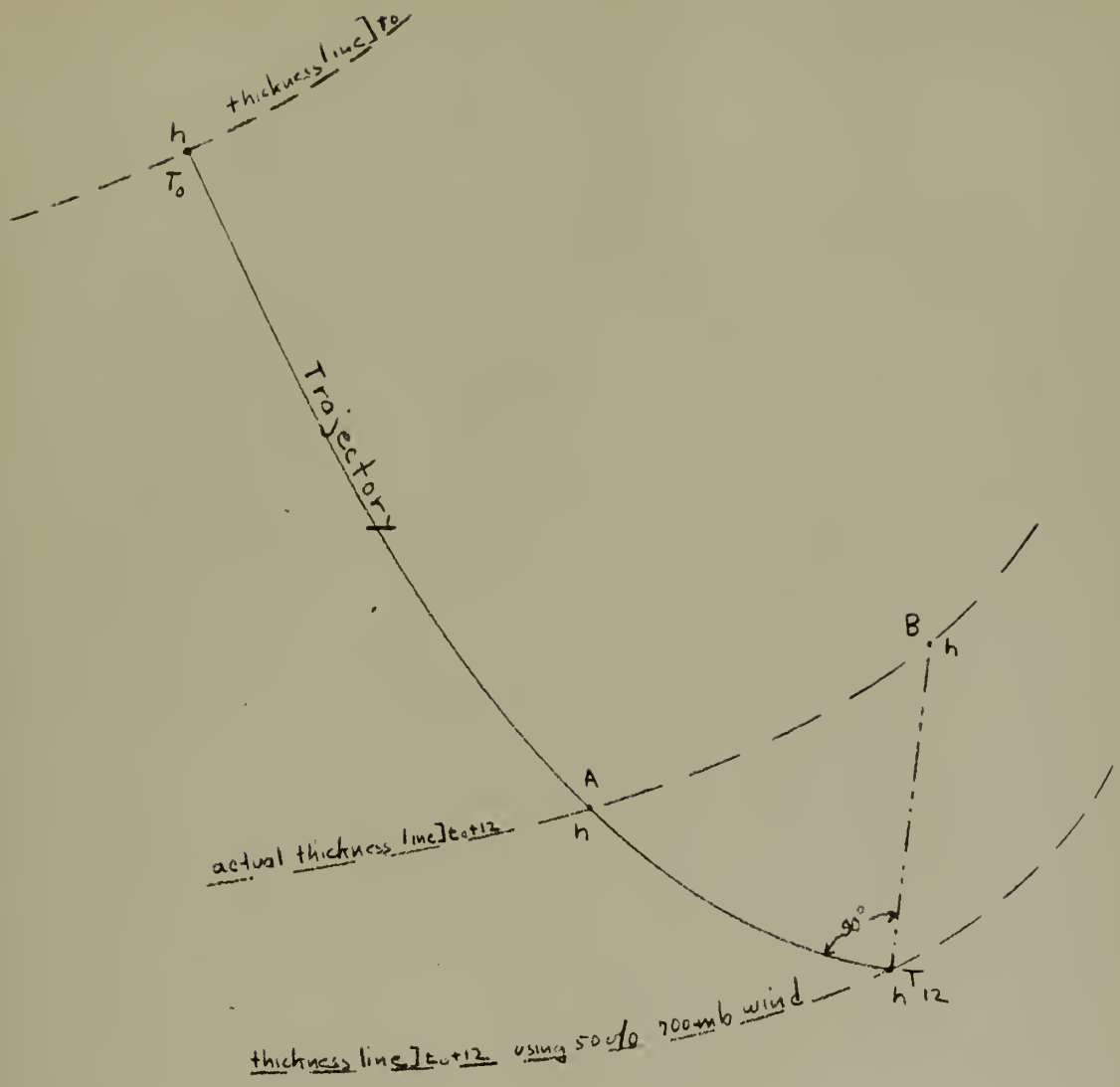


FIG. 1(b) VERTICAL VELOCITY AT 500 MBS (CM/SEC)

3. Evaluation and Results.

As stated in Section 2., there must be some method of quantitatively assessing the departure from 50% advection of the thickness pattern. It was decided to use relative "difference" as the basic parameter to be measured. Essentially, the ratio of actual displacement of a discrete value of thickness, to that displacement achieved by advecting with 50% of the geostrophic wind, and multiplying the resultant fraction by 100 gives 100 plus the relative difference in percent. Since, in numerous cases, there appeared to be large movements of thickness values normal to the wind, an alternate method of evaluating relative difference was employed. It consisted of taking the ratio of the distance normal from the end of the 50% advection trajectory to the thickness line in question, to the 50% advection displacement, and multiplying the result by 100. Usually, both methods worked for the same individual case thus giving a two-valued "fix"; but occasionally, with large lateral displacements of thickness lines, measurement along the trajectory as prescribed by the first method was impossible. These procedures are illustrated in Fig. 2.

Thus, the initial measurements and evaluations were applied to a body of sample data. This data was obtained directly from a series of analyzed charts received from the NWAC unit, Suitland, Maryland via facsimilie. Specifically, the charts consisted of (1), 0300Z and 1500Z 700-mb and 500-mb; (2), 0630Z and 1830Z surface, upon which were superimposed the 0300Z and 1500Z thickness patterns immediately preceding. The months of December 1956 and January 1957 were used for the sample data. There was no attempt in this case to study seasonal effect, or to make seasonal comparisons. The early winter months were chosen, however, so there would be an abundance of cases of strong warm and cold advection



$T_0 T_{12}$ = Displacement with 50% advection by 700-mb geostrophic wind.

$T_{12}A$ = Absolute difference along trajectory.

$T_{12}B$ = Absolute difference normal to trajectory.

$D_T = \frac{T_{12}A}{T_0 T_{12}}$ = Relative difference along trajectory.

$D_N = \frac{T_{12}B}{T_0 T_{12}}$ = Relative difference normal to trajectory.

h = discrete values of thickness.

Fig. 2 - Measurement of Relative Difference.

with all of the dynamic and adiabatic processes being present. Thus, a sufficient quantity of sample data could be collected with a minimum of searching through long sequences of charts.

A total of 502 cases of advection were evaluated. First, the advection was classified into type, i.e., warm and cold. The geographic subdivisions were then provided, viz., Pacific Ocean, Continental United States and Canada east of the Rocky Mountains, and the Atlantic Ocean. Excluded in this investigation were the western mountain and plateau regions because of the high terrain, and ocean areas west of ship "P" and east of ship "C". In the ocean areas covered, care was taken to obtain data only where the synoptic patterns were strongly indicated by sufficient observations provided by ocean station vessels and weather reconnaissance flights.

The advection was then subclassified into type of major flow in which the advection was occurring. The flow type was determined by inspection of the 500-mb chart, and designated according to position relative to the major troughs and ridges. The following flow types were observed to have enough cases of advection associated with them to warrant investigation: Trough to inflection (T-I), inflection to ridge (I-R), and inflection to trough (I-T). Cases occurring with ridge to inflection flow were infrequent and finally were combined with inflection to trough categories in the application of the results. Blocks and closed centers were not included in this categorization because the number of cases of advection in the immediate areas of these circulations were relatively few.

In order to study the effects of condensation and precipitation, warm advection cases over the United States were subdivided into cases where precipitation was occurring, where there was overcast or broken

clouds generally prevalent over the area, and those cases of warm advection where the skies were clear or scattered. This was done here in lieu of subdividing with regard to major flow. However, most of the cases of warm advection with clear or scattered sky conditions occurred under inflection to trough flow, especially with the "dry fronts" of the plains regions where modified polar Pacific air overruns cold continental polar. Cold advection cases were not studied with regard to precipitation, since earlier investigations [5] established little effect of precipitation on cold advection. Also, in this present study, the sub-classification with regard to clouds and precipitation was not accomplished over the ocean areas, because the lack of sufficient reporting stations made the differentiations extremely subjective.

The basic statistical problem in this investigation was essentially threefold. First, it was necessary to establish, within a certain degree of confidence, whether or not a definite positive or negative correlation exists between the departure from 50% advection of 12-hour movements of thickness values, and the vertical velocity at 500 mbs. under which this advection is taking place. Then, if such a correlation can exist, the problem was to ascertain the confidence limits of the population correlation coefficient based on the given sample. Finally, using the sample correlation coefficient, standard errors of estimate were calculated in order to determine the usefulness of each classification as a prognostic aid, and to combine categories that had similar characteristics.

After sorting out the sample measurements and placing them into the individual categories previously mentioned, scatter diagrams were constructed. The vertical motion in centimeters per second under which the advection was taking place was scaled along the abcissa of the diagram.

The relative difference being the dependent variate was scaled along the ordinate. The origin was placed at the intersection of the two axes where the vertical velocity is zero and where the advection is 50%, i.e., relative difference zero.

The constructed diagrams were then inspected to determine which of the categories appeared to display any correlation at all. Those which did not were not treated further, except that a mean and standard deviation of the dependent variate were computed. Table 1 shows these results.

For those categories showing some indication of either positive or negative correlation, sample correlation coefficients were computed using standard procedures found in any statistical reference, e.g. [6]. With the given sample size and sample correlation coefficient, the hypothesis that a correlation coefficient for the population from which the sample was drawn does not equal zero was tested using a 95% confidence coefficient. This was done by using a graphical procedure [7]. If the resulting confidence limits at the 95% level included zero as a correlation coefficient the hypothesis was rejected. Of the six categories which originally showed some degree of correlation, one was initially rejected, mainly because its sample correlation was very low, (0.09). However, upon combining this category with another similar to it, the confidence limits were re-established for the new sample within the region of acceptance of the hypothesis.

Sample regression curves were then fitted to the data in each group, by the method of least squares. A straight line of the form $Y = a + bX$ was found to be the best suited. Standard errors of estimate were computed for each regression. The results for these categories

Table 1.

Results for Categories from which

No Significant Correlation was Obtained.

Category	Pacific Warm I-R	Pacific Cold I-T	Atlantic Warm I-R	U.S. Warm ovc.-brkn. no precip.	U.S. Warm precip.
	(rel. difference along trajectory)				
n	36	29	28	70	60
$\bar{W}$	+1	-1	+0.5	+0.5	+0.5
$\bar{D}$	-46%	-113%	+15%	-11%	-2%
s	47%	71%	61%	73%	51%
	(rel. difference normal to trajectory)				
n	36	27	35	65	66
$\bar{W}$	+1	-1	+0.5	+0.5	+0.5
$\bar{D}$	34% (cooling)	54% (warming)	9% (warming)	1% (cooling)	1% (warming)
s	42%	37%	60%	52%	48%

and the combined categories are presented in Table 2. Figures 3 through 10 inclusive show the fitted regression lines of relative difference on vertical velocity.

The results show that even with those categories which displayed some degree of correlation, only semi-quantitative statements can be made concerning the prognosis of thickness lines. In the cases with correlation, the sample coefficients are at best only moderately strong, and are themselves subject to rather wide confidence limits. The standard errors of estimate for the samples are too excessive to allow the regression equations to be applied directly in prognostic work. Those categories which were uncorrelated, have large standard deviations and the results can be used only as a rough guide in the prognosis.

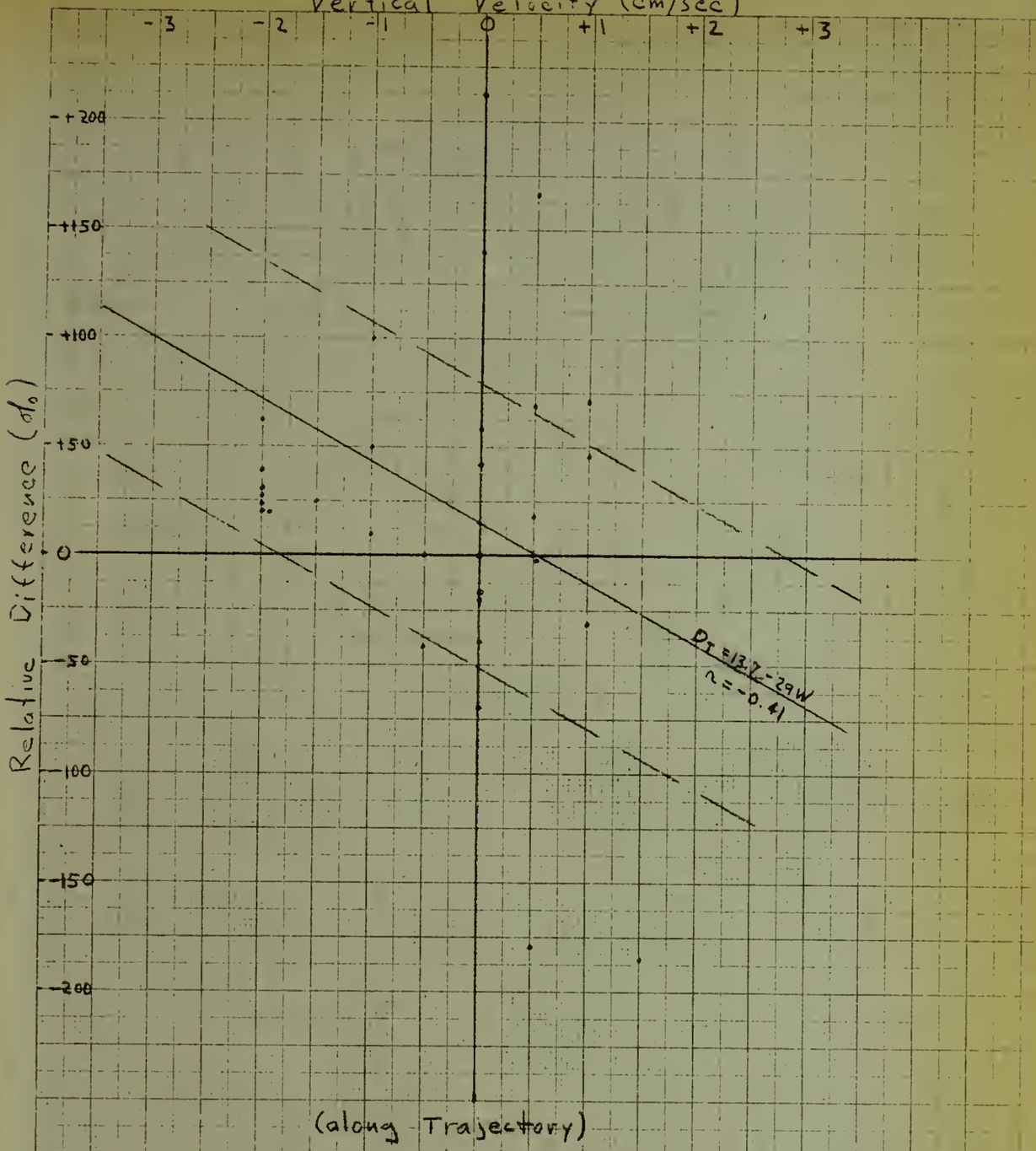
One reason for the rather poor correlations and large deviations apparently lies in the various non-adiabatic processes which were not accounted for such as radiation and convective heat transfer. Another important reason for large variations of course can be attributed to errors of analysis and prognosis of the basic charts which are carried along in the thickness prognosis.

Other sources of error lie in the approximation of total advection in the layer by a single level, in this case 700 mbs., and in the construction of the vertical velocity charts which embody the assumptions intrinsic in the thermotropic model from which the chart is derived. Since over the prognostic interval the fields of vertical velocity usually moved faster than the 50% advection of thickness lines, interpolation with respect to time was necessary to arrive at representative values of vertical velocity for each case of advection. This, too, introduced some error. In some categories, especially those of warm advection,

Table 2.

Results for Categories from which Significant Correlation was Obtained.

Category	Atl. Warm T-I.	U.S. Warm clear	Atl. Cold I-T.	U.S. Cold I-T.	Atl. Cold T-I.	U.S. Cold T-I.	Comb. Cold I-T.	Comb. Cold T-I.
	(rel. difference along trajectory)							
n	32	18	38	64	33	55	102	88
r	-0.41	-0.68	+0.48	+0.09	+0.42	+0.57	+0.27	+0.49
C.L. for ρ at 95% level	-0.66 to -0.05	-0.86 to -0.33	+0.19 to +0.68	-0.17 to +0.34	+0.07 to +0.66	+0.38 to +0.77	+0.08 to +0.44	+0.33 to +0.64
S	71%	35%	68%	70%	53%	36%	72%	43%
	(rel. difference normal to trajectory)							
n	40	35	44	74	43	64	118	107
r	-0.57	-0.59	-0.43	-0.30	-0.63	-0.58	-0.32	-0.59
C.L. for ρ at 95% level	-0.75 to -0.32	-0.77 to -0.32	-0.65 to -0.16	-0.44 to -0.08	-0.78 to -0.40	-0.72 to -0.39	-0.46 to -0.12	-0.70 to -0.47
S	38%	37%	52%	37%	34%	40%	45%	38%



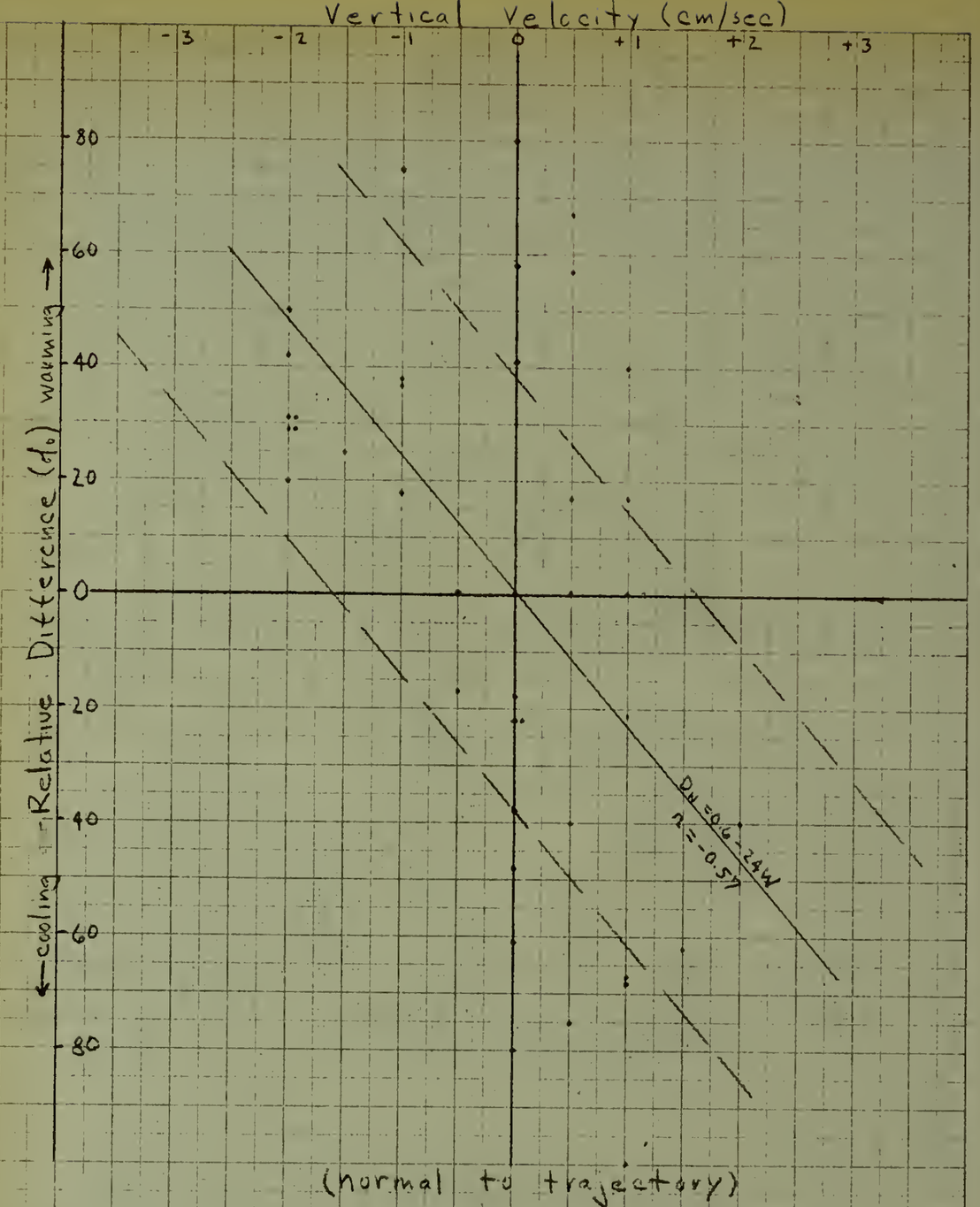
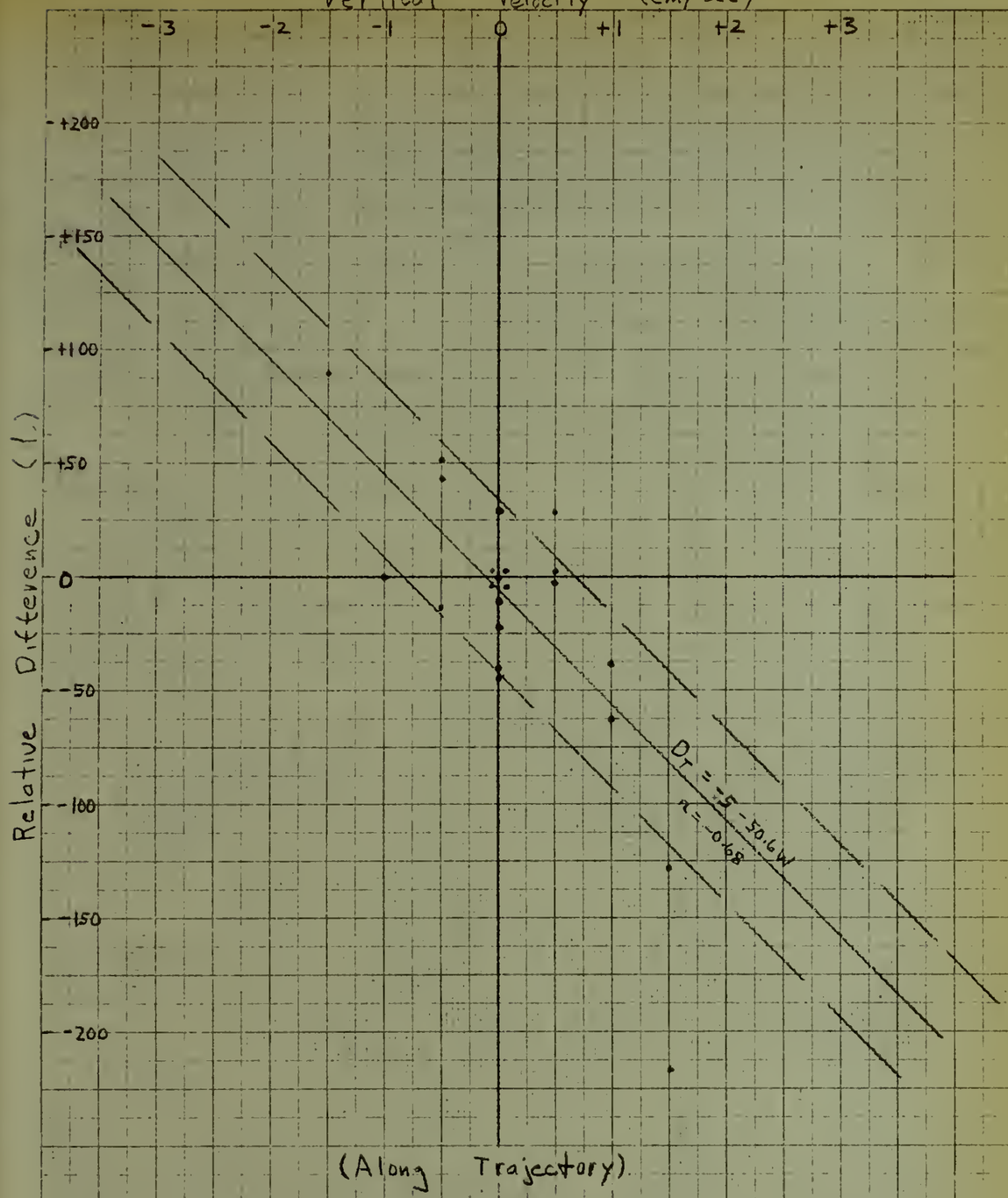


Fig 3 Regression of Relative Difference on Vertical Velocity
Category: Atlantic Warm, Trough to Inflection



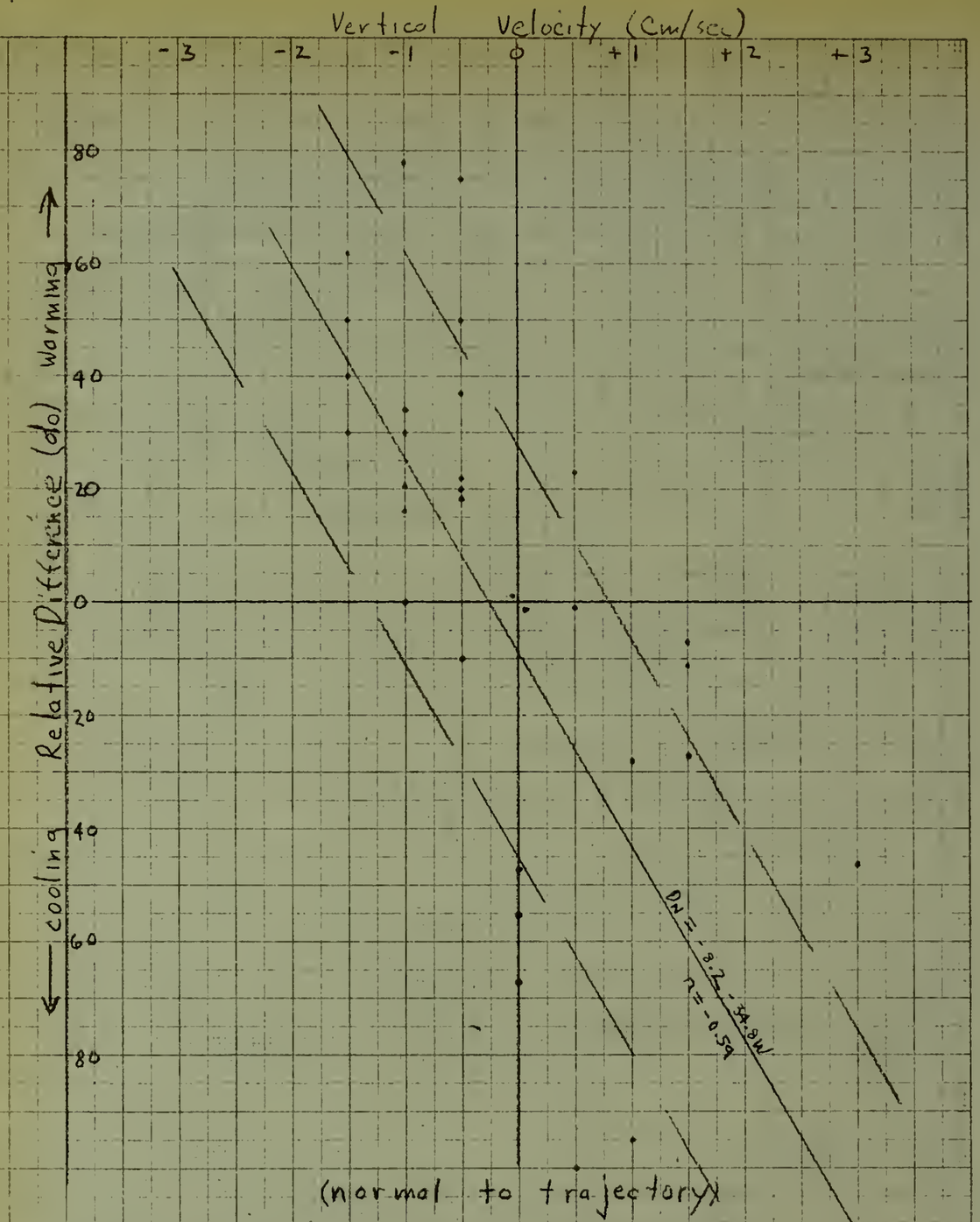
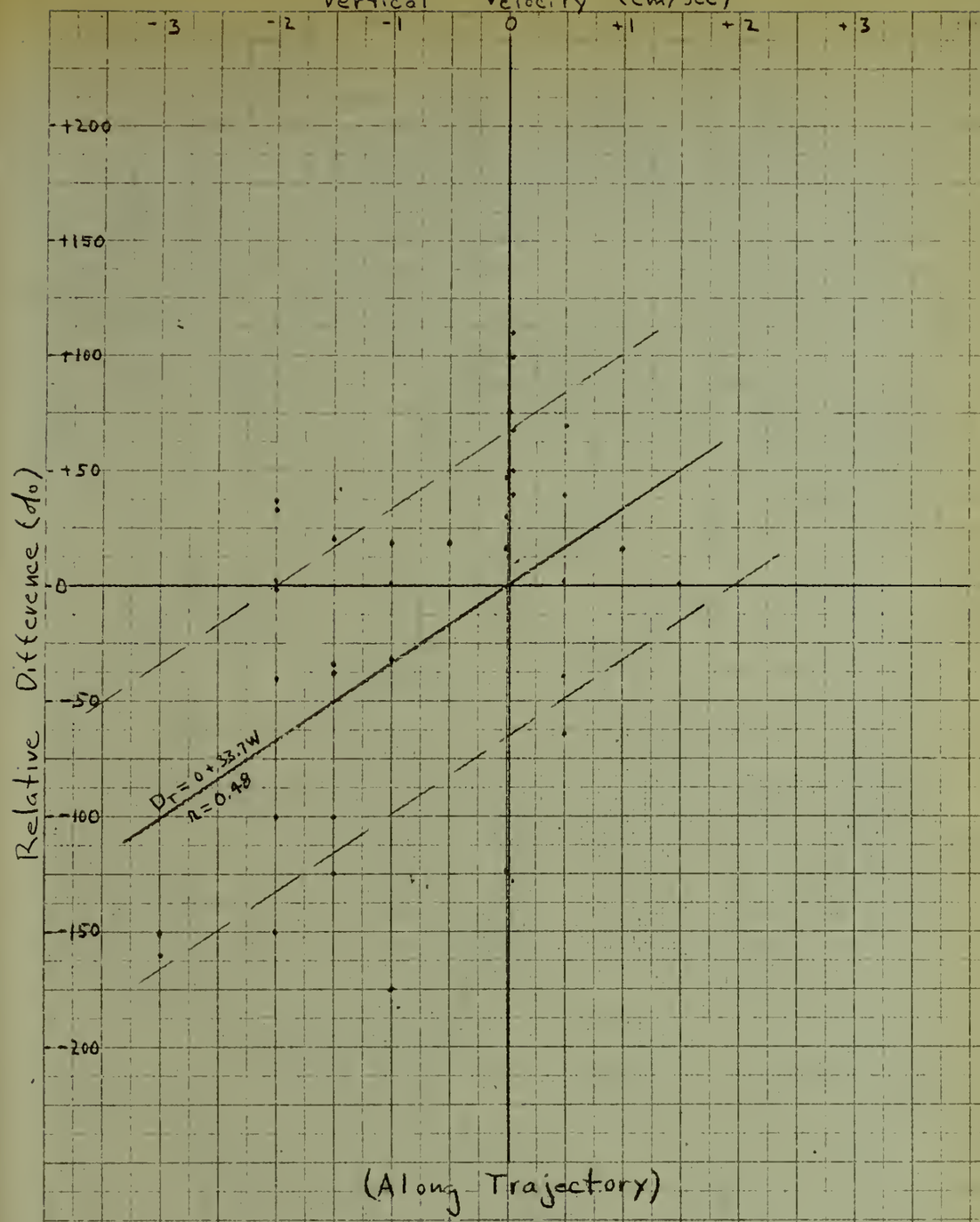


Fig 4: Regression of Relative Difference on Vertical Velocity
Category: U. S. Warm, Clear or Scattered Clouds



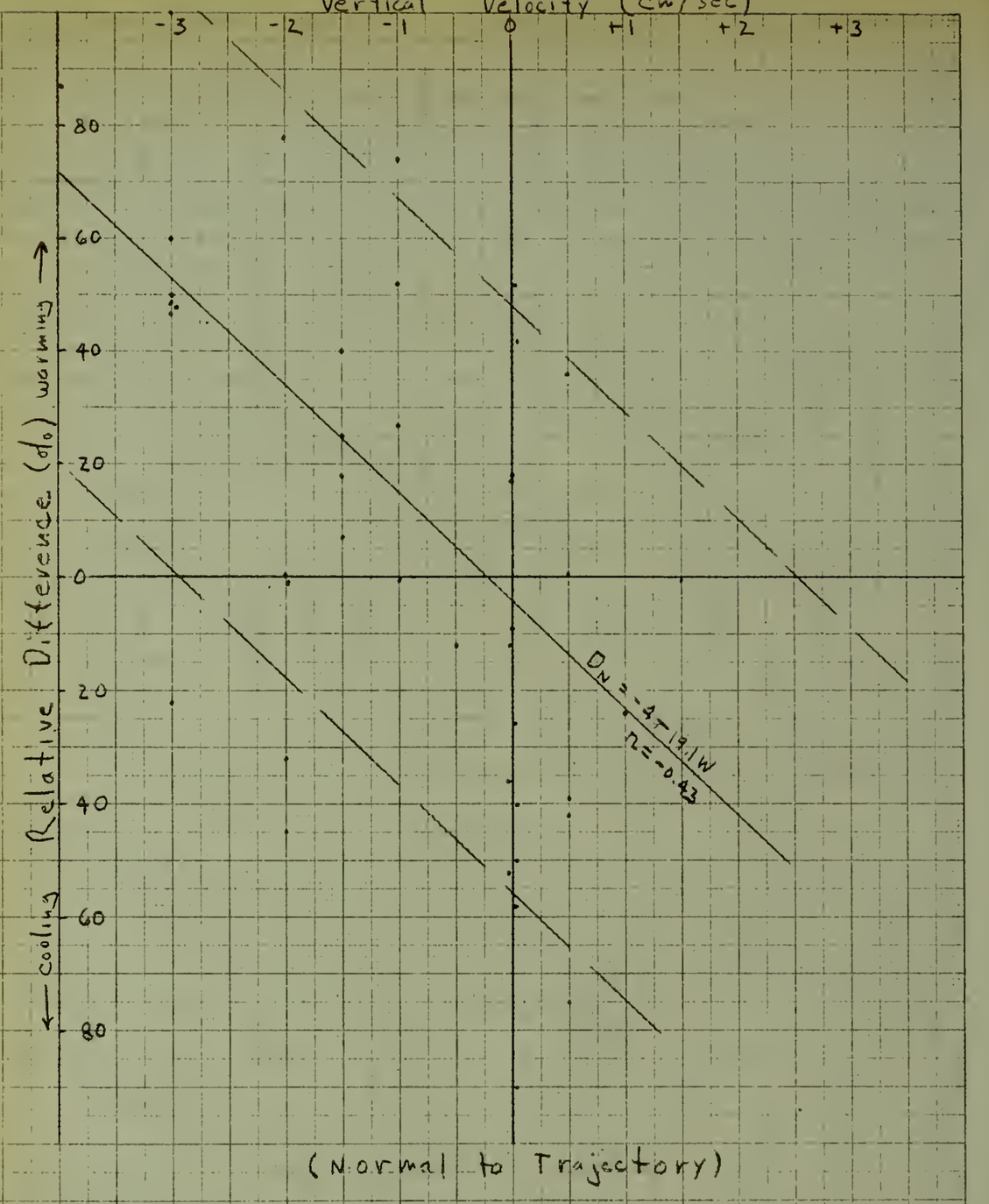
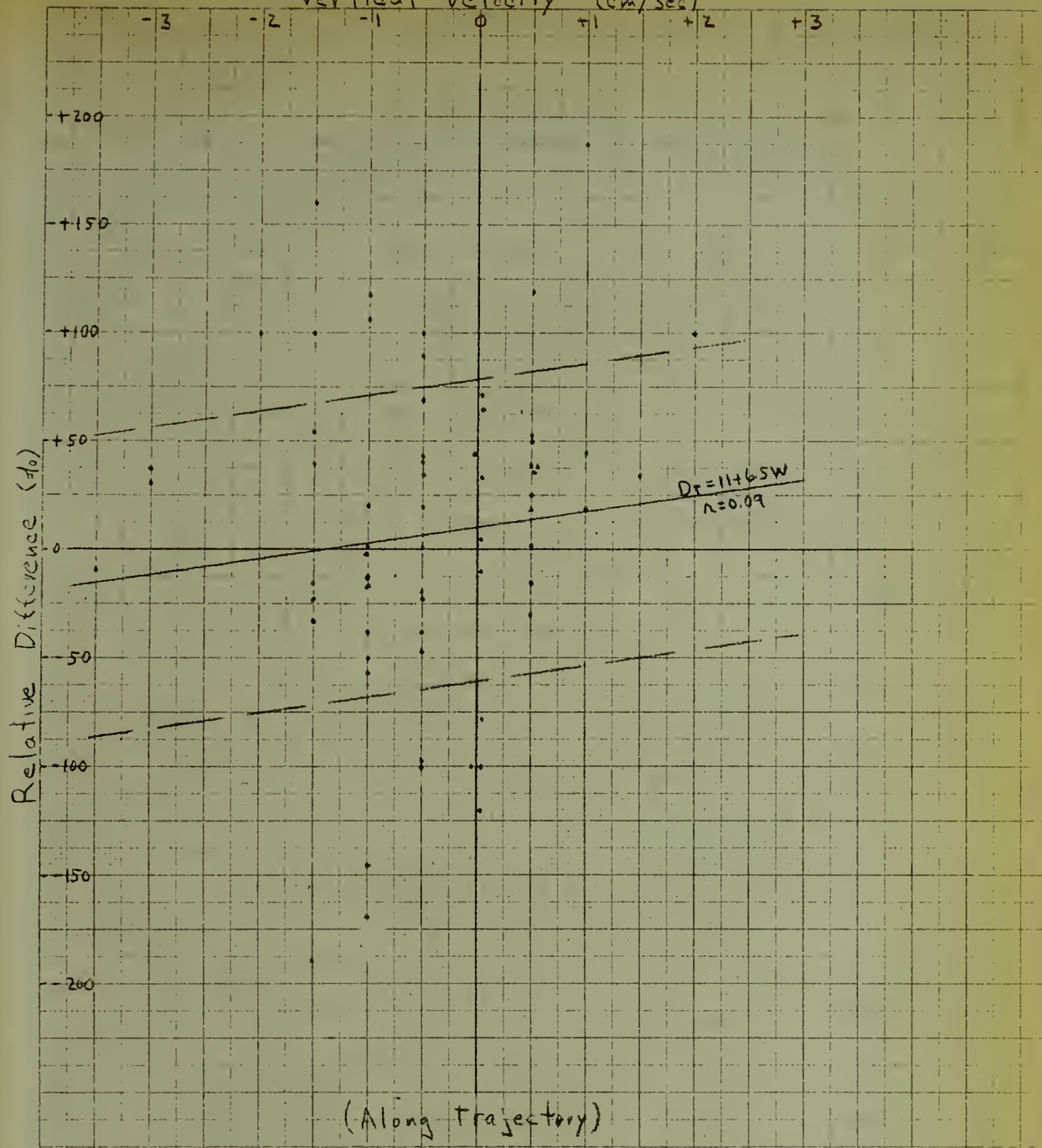


Fig 5: Regression of Relative Difference on Vertical Velocity

Category : Atlantic Cold, Inflection to Trough



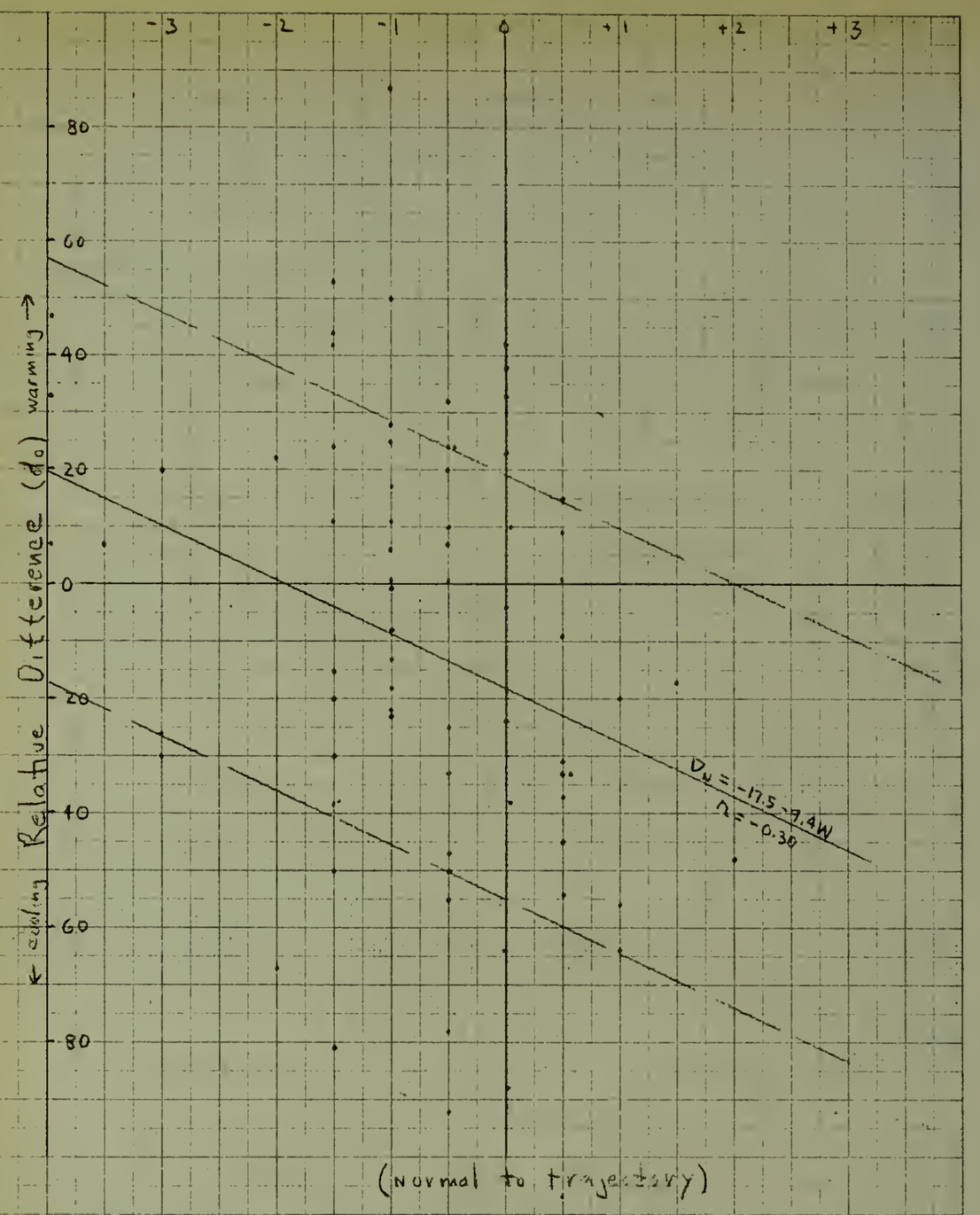
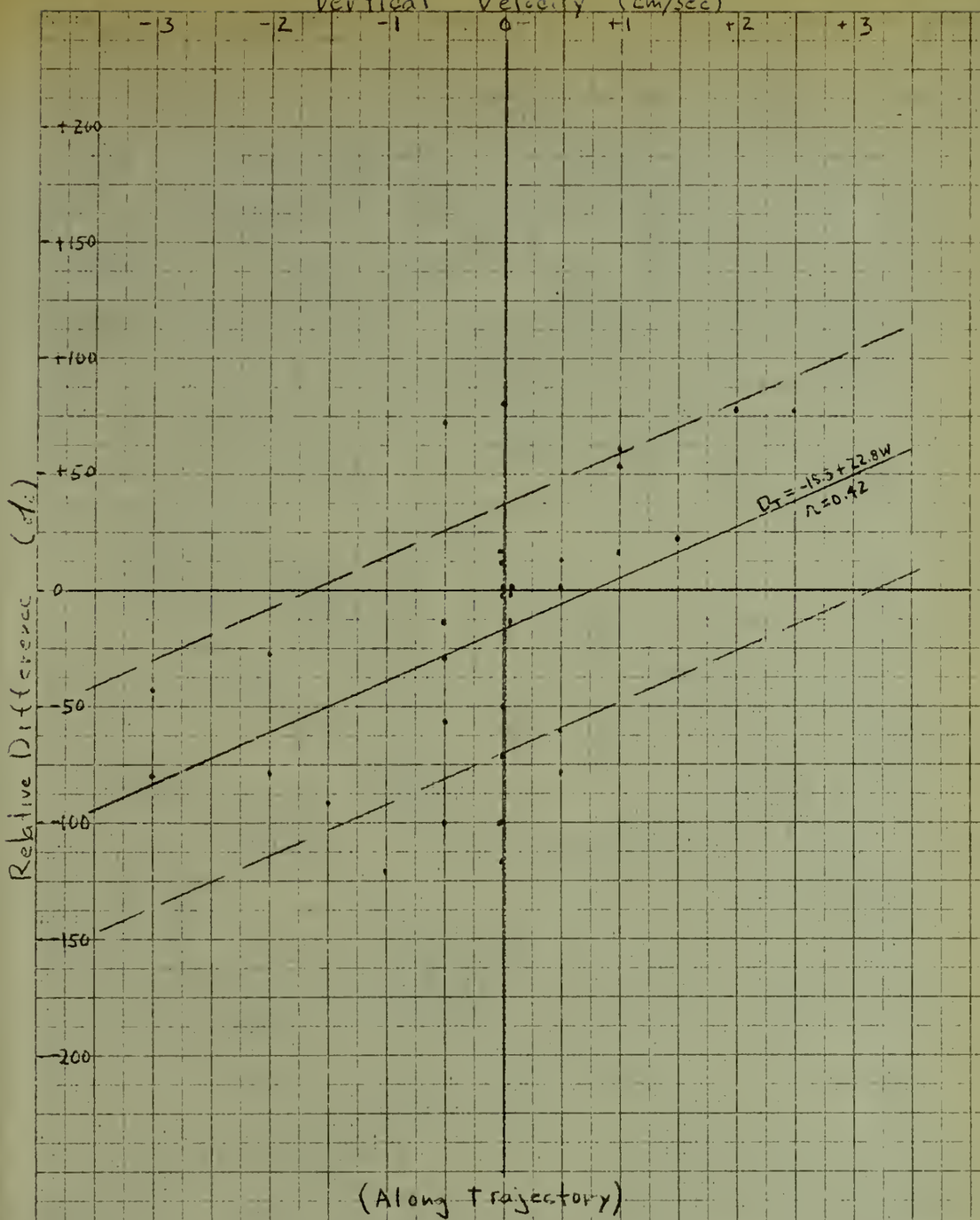


Fig 6: Regression of Relative Difference on Vertical Velocity
Category: U. S. Cold, Inflection to Trough



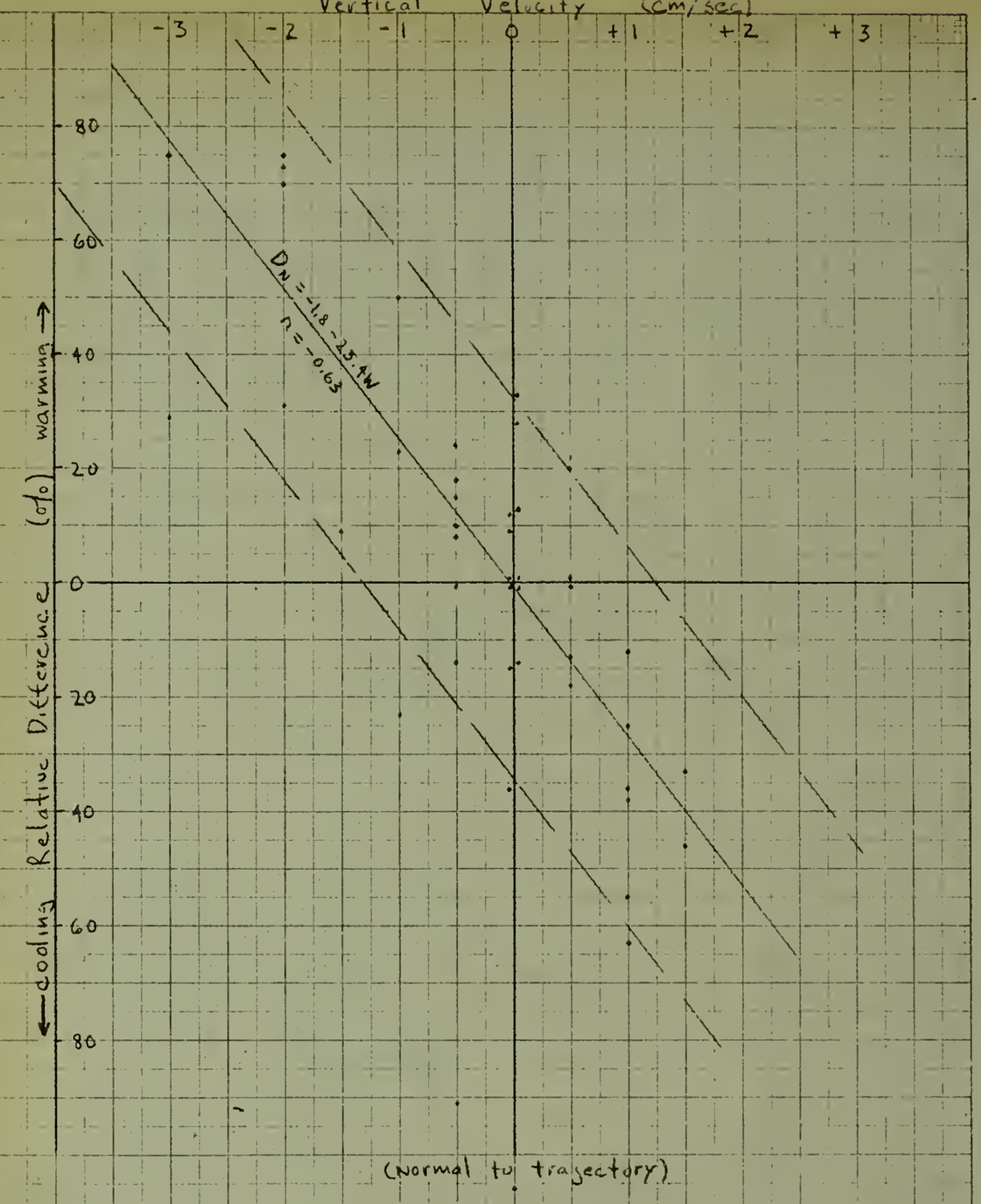
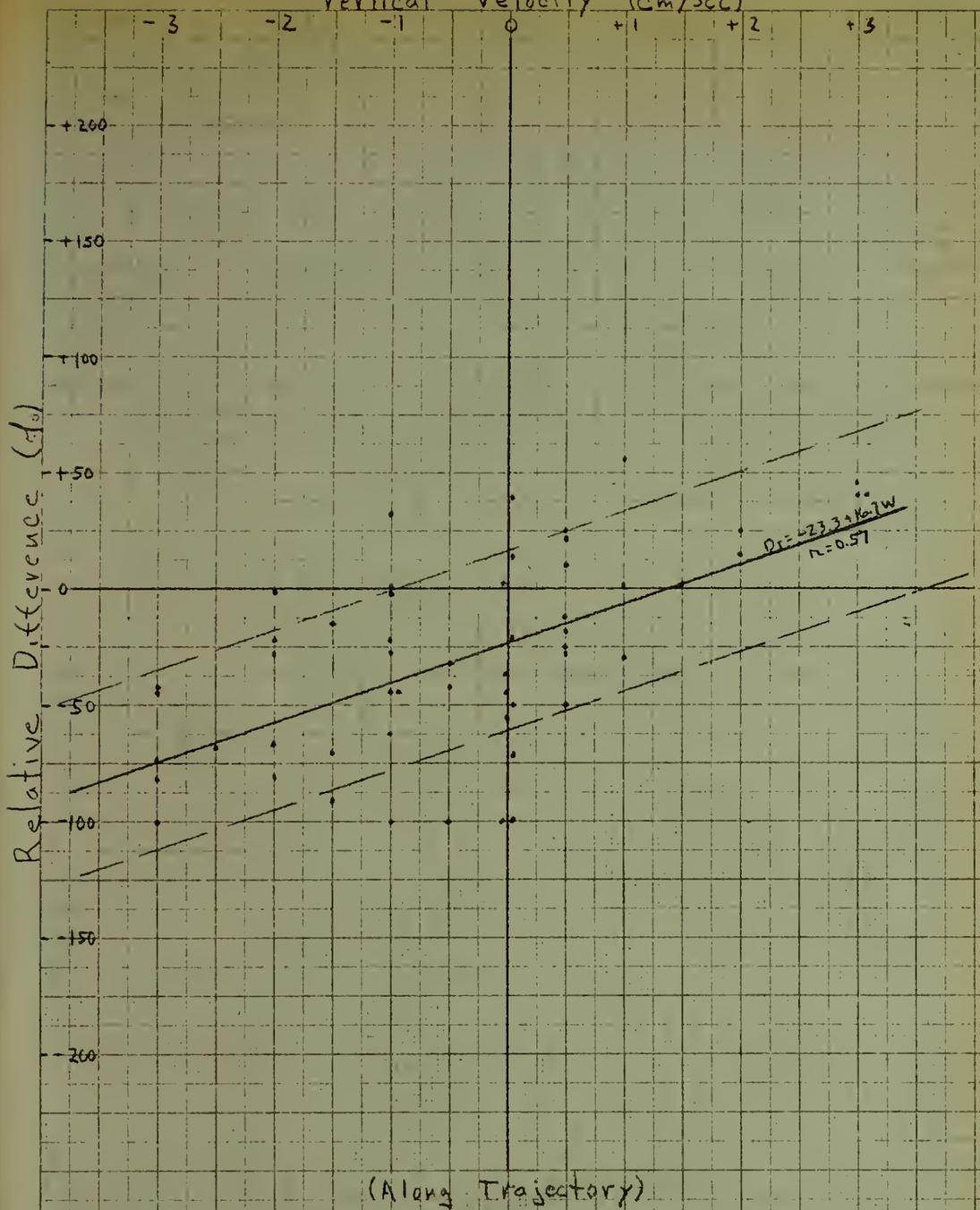


Fig 7: Regression of Relative Difference on Vertical Velocity
Category: Atlantic Cold, Trough to Inflection



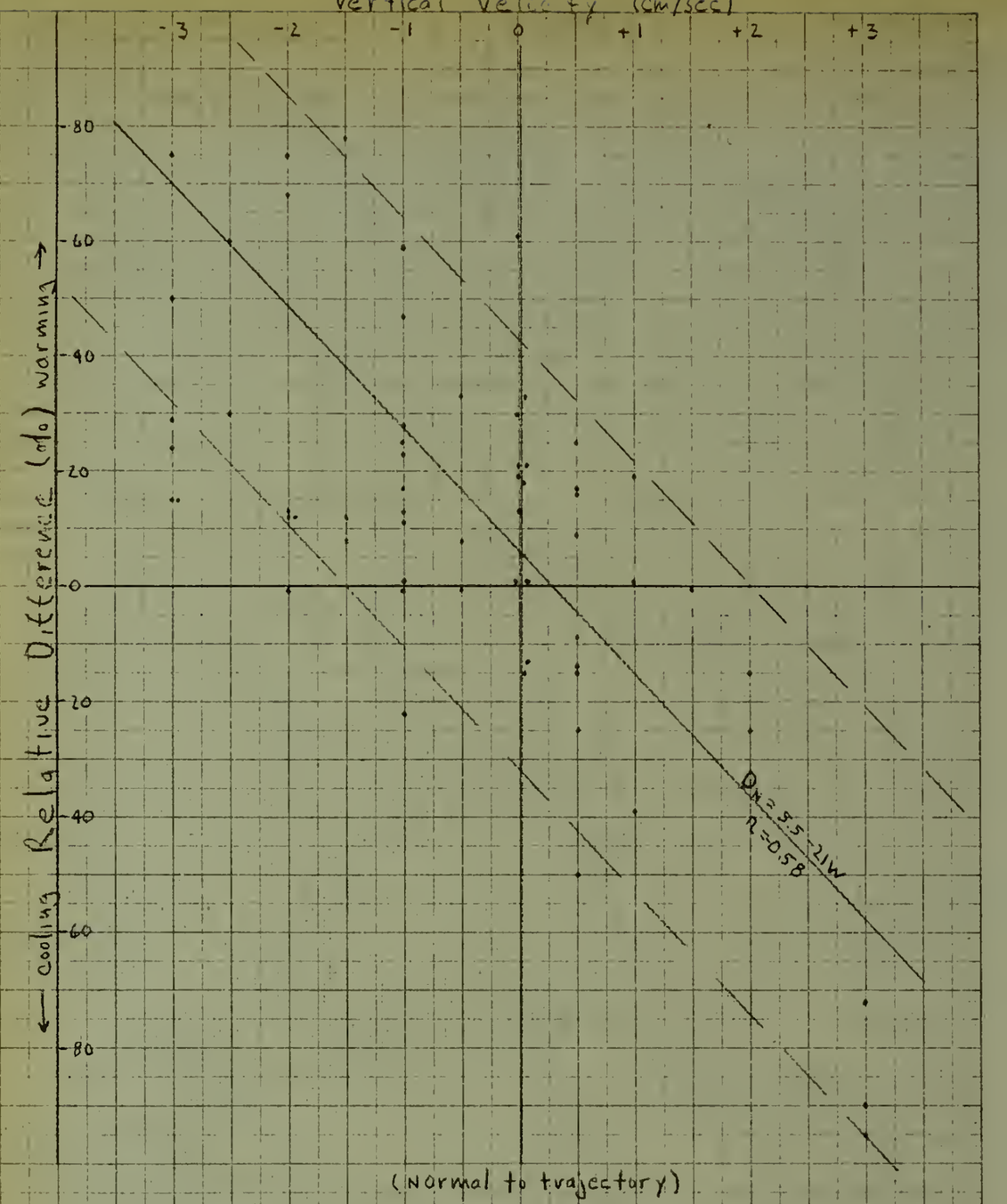
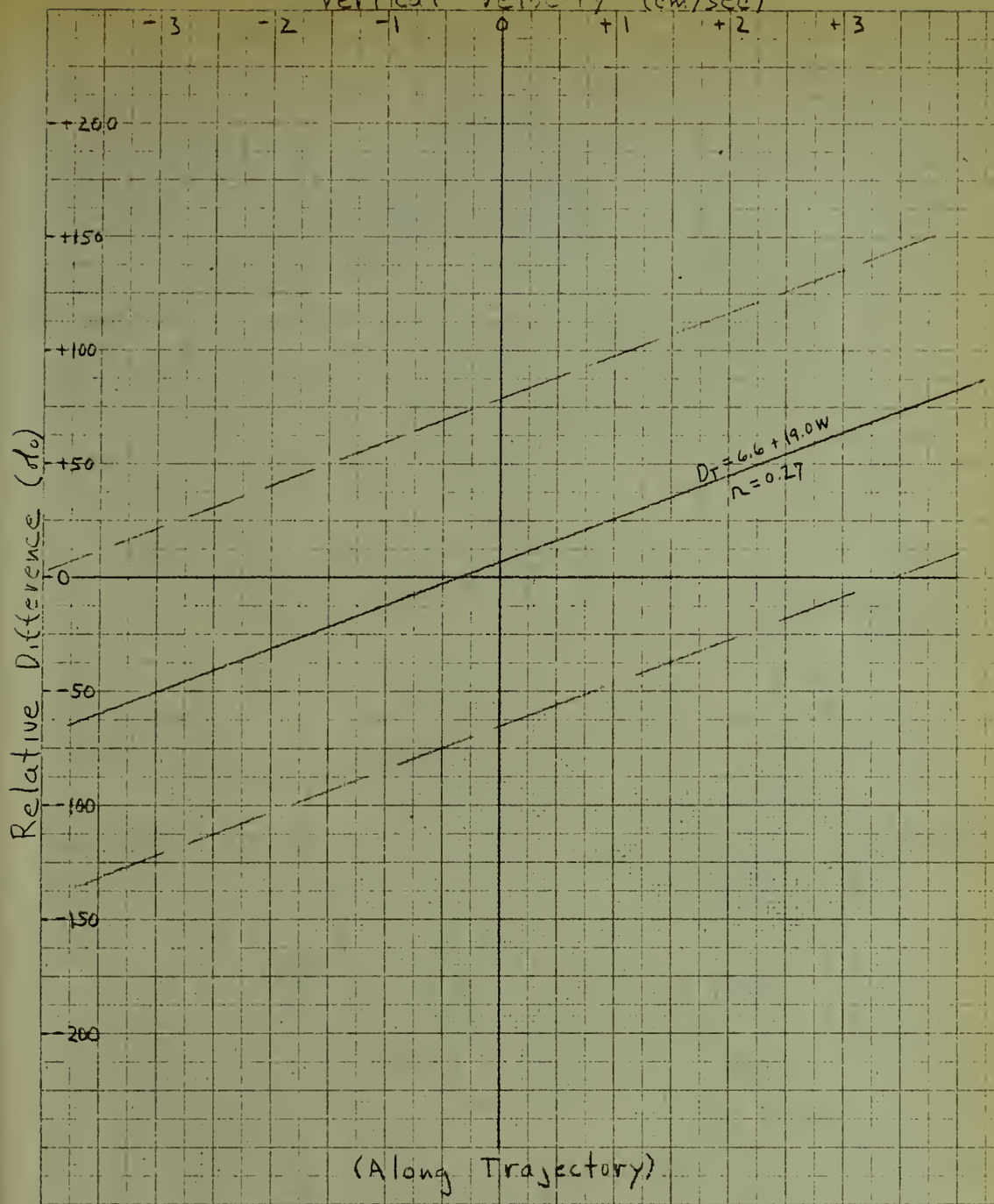


Fig 8: Regression of Relative Difference on Vertical Velocity
Category: U.S Cold, Trough to Inflection



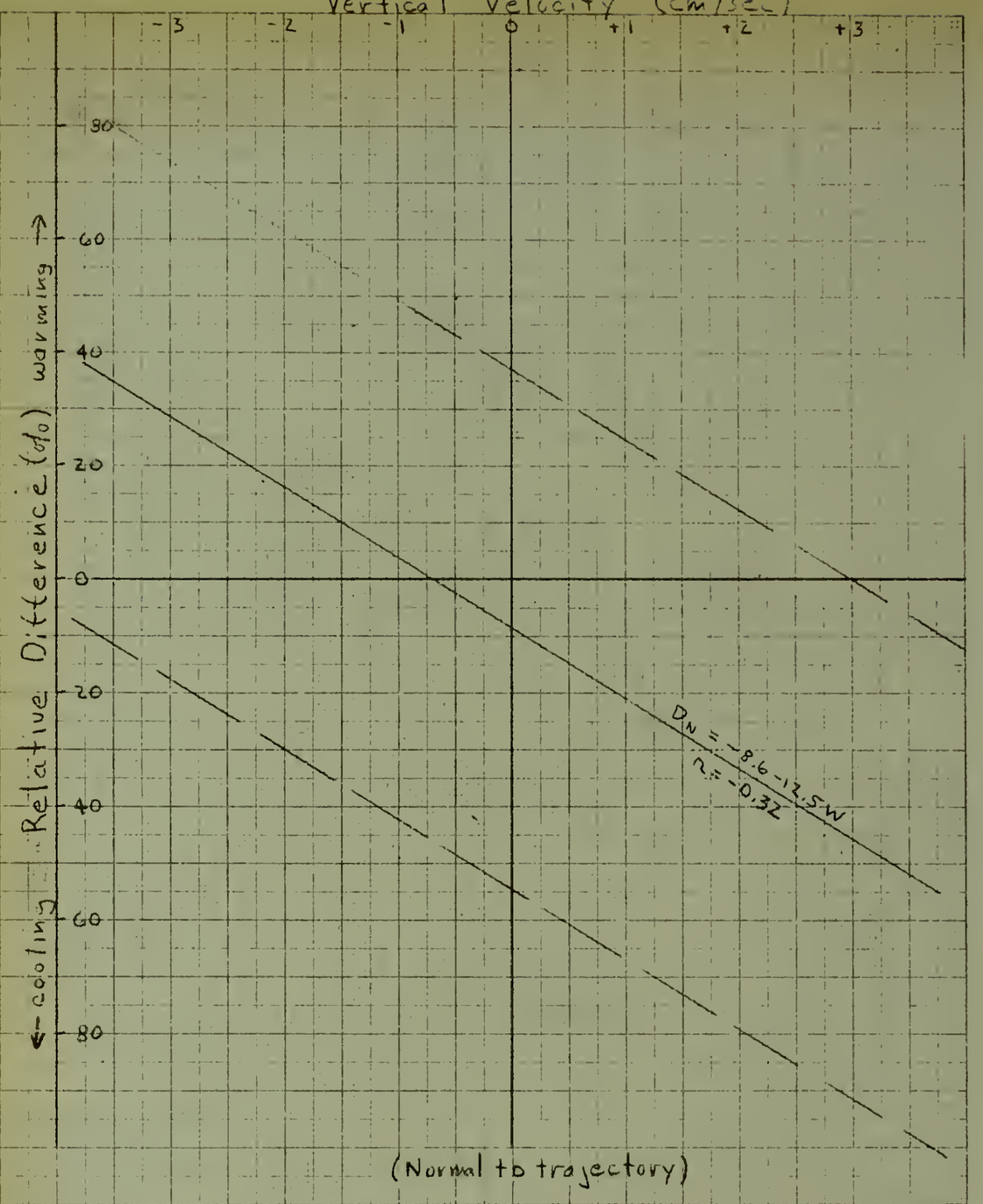
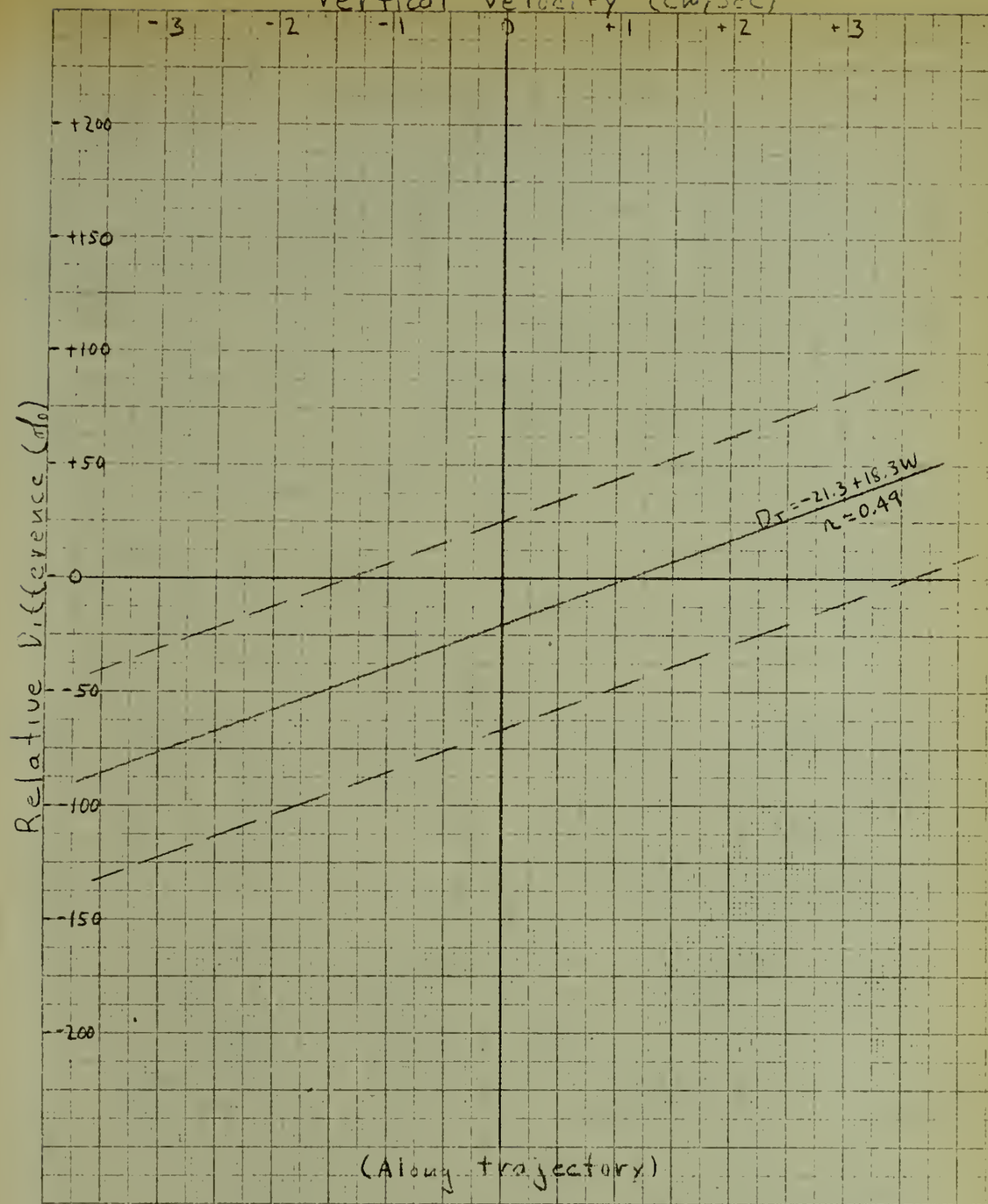


Fig 9: Regression of Relative Difference on Vertical Velocity
Category: Combined, Cold, Inflection to Trough



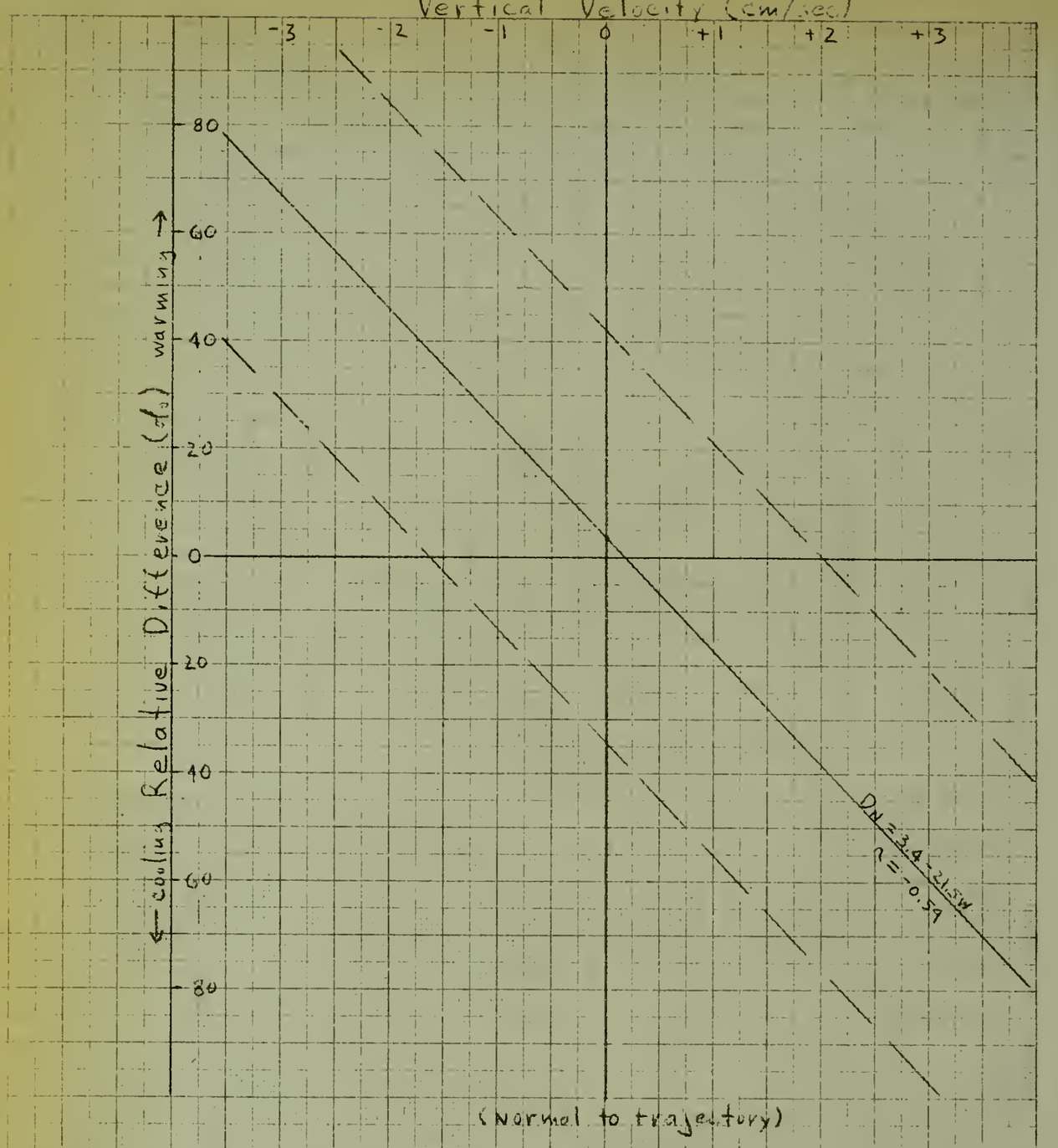


Fig 10: Regression of Relative Difference on Vertical Velocity

Category: Combined, Cold, Trough to Inflection

vertical velocities seldom exceeded 1.5 centimeters per second. Since the areas are delineated to the nearest whole value of vertical velocity, functional relationships between the variables were difficult, if not impossible to detect.

In comparing the various categories it was found that correlation was practically non-existent in the cases with precipitation or cloudiness other than scattered, or in the cases of areas where warm advection was not differentiated with respect to cloudiness or precipiation. The one exception to the above was in the category Atlantic, warm, T-I, where the correlation was fair. This was due to the relatively large number of cases with no precipitation and few clouds. This shows that the single effect of vertical ascent in modifying thickness tendencies is overshadowed by the effects of environmental lapse rates, and the saturated adiabatic processes with attendant effects of condensation and precipitation.

Other areas of weak correlation besides those in the Pacific Ocean (where the scarcity of data and lack of well defined areas of advection resulted in poor measurements and small sample sizes) were in the I-T categories of cold advection. The major hindrance to good correlation have appeared to be due to the cases of fresh polar outbreaks. Here, advection of the thickness lines was far in excess of the 50% factor even under strong subsidence at 500 mbs. A few cases showed nearly 100% advection. This appears to be caused by the strong influx of cold dense air at lower levels overriding the effects of warming due to subsidence. However, as soon as the cold advection rounded the trough and entered a T-I classification, the effects of vertical velocity were more contributory to the modification of thickness change, and correlation

between the two improved as is shown. This suggests that vertical motion at 500 mbs. has a delaying action on affecting the movement of thickness lines of the 1000-mb to 500-mb layer; and the effect becomes pronounced only after the polar outbreaks have lost some of their original strength.

Similarities between categories appeared to be strongest with regard to similar positions under the 500-mb flow pattern rather than with respect to same geographic area. Thus both U.S. and Atlantic T-I categories of cold advection were grouped as "Combined T-I". In fact, the two categories of cold I-T for the U.S. and Atlantic were combined, and the resultant 95% confidence limits for accepting the hypothesis of correlation of the grouped sample fell within the acceptable range, whereas in the single category of U.S., cold, I-T, the hypothesis of correlation was denied. This appears to show that the differences between heat exchange over land and over water have comparatively little effect on the entire 1000-mb to 500-mb layer.

The best correlation was found for the warm advection category over the U.S., not accompanied by precipitation or clouds in excess of "scattered". This appears due in part to the accuracy of analysis over the U.S. and the absence of the complicating effects of condensation and precipitation. Also the airmasses involved were evidently dry and stable so that vertical ascent was almost always associated with negative tendencies, or cooling, thus enhancing a negative correlation.

All other categories presented had no correlation, but the mean and standard deviations of each sample do indicate various departures from 50% advection, in broad agreement with theory.

4. Application and Test.

Using the results as shown in Section 3, certain modifications can be applied to a basic advection of the thickness lines with 50% of the 700-mb winds. Table 3 presents such modifications. Where significant correlation was obtained in the preceding treatment, i.e., the cases of cold advection, I-T and T-I, and warm advection with clear or scattered clouds, percentage adjustment of the 700-mb advection are presented opposite values of vertical velocity. Cases where there was no correlation, a percentage adjustment is given for each specific advection type, to be used without regard to the vertical velocity. Since data over the Pacific Ocean was scarce, and there appeared to be relatively little to distinguish advection over the Atlantic Ocean from advection over North America with respect to the vertical velocity field, each adjustment is considered to apply everywhere including the western plateau and mountain region. Although the effects of high terrain, warm bodies of water, etc., in modifying thickness patterns are not denied, such investigations were not conducted in this study except for the categorization into continental and oceanic areas. Here, the difference between categories were not statistically significant, except for type of upper flow and, in the case of warm advection, the occurrence of clouds and precipitation.

For adjustments along the trajectory, the percentages given are that of the total 700-mb advection. Adjustments normal to the trajectory are in percentages of trajectory length using 50% advection. These latter adjustments need be applied only when it becomes difficult or impossible to apply corrections along the trajectories, for example, when the wind is parallel to the thickness lines, or, in cases where

Table 3.

Percentage Adjustments to Apply to the Advection of the 1000 to 500-mb Thickness by the 700-mb Wind.

A. Advection types significantly correlated with W (cm/sec)

Cold Advection, I-T			Cold Advection, T-I			Warm Advection, clear or scattered		
W	%(T)	%(N)	W	%(T)	%(N)	W	%(T)	%(N)
-3	25	30w*	-3	10	65w	-2	100	60w
-2	35	15w	-2	20	45w	-1	75	30w
-1	45	5w	-1	30	25w	0	50	0
0	55	10c	0	40	5w	+1	25	35c
+1	65	20c	+1	50	20c	+2	0	65c
+2	75	35c	+2	60	40c			
+3	85	45c	+3	70	60c			

* w refers to a displacement associated with greater warming, (or less cooling), than indicated by the basic 50% advection, whereas c refers to greater cooling (or less warming).

B. Advection types having insignificant correlation with W (cm/sec)

(1) Warm advection, overcast or broken : 40%(T)

(2) Warm advection, precipitation : 50%(T)

(3) Cold advection, fresh polar outbreaks : 80%(T)

the wind is tangent to curved thickness lines such as across the axes of thermal troughs or ridges. In these cases it is impossible to distinguish advection type since actually there is no real advection at these particular points. But adjustments are nevertheless necessary here in order to arrive at an improved prognostic pattern. Since the adjustments are presented in Table 3 under advection types, the choice of type remains subjective. It will suffice to state here that, in general, it is best to apply the corrections assuming that advection of the type occurring immediately upstream from the area in question is present, and then to proceed to apply the adjustments normal to the trajectories. Thus, at the crest of a thermal ridge, where in effect warm advection is being replaced by cold advection, adjustments apropos to cold advection under the specific flow pattern should be applied.

With regard to the case of "fresh polar outbreaks", distinguishing this type of advection from other types of cold advection is subjective. Wintertime cases with strong north or north-westerly flow of continental polar and continental and maritime arctic air-masses should be included in this category. Modified polar air-masses, of "age" greater than two days should no longer be classified as "fresh", and adjustments according to the vertical velocity should then be applied. Also excluded from this category are minor polar outbreaks, and outbreaks occurring in seasons other than winter, late autumn, or early spring.

A series of analyzed charts for the month of November, 1956 was used to test the results. Specifically, the forecast intervals were from 0300Z to 0300Z, 2-3 November, and 11-17 November inclusive, or seven 24-hour periods. These particular dates were chosen because of the

number of areas of strong warm and cold advection encompassing Pacific, Atlantic and continental areas. Coupled with this were enough active areas of vertical velocity at 500 mbs. to make the test significant. A grid currently in use at the U. S. Naval Postgraduate School, Department of Aerology, to compute verification scores for prognostic charts was applied in these tests. However, the grid was extended about 600 miles eastward to allow more Atlantic coverage. This particular grid is shown in Fig. 11. Actual and prognosticated values of thickness are taken from each point. From each value obtained the value for the neighboring point east and south are subtracted thus giving a measure of the thickness gradient. Each gradient determined from the prognosticated values is then compared with the gradient determined from the actual values and an absolute difference is obtained for each pair of values. The difference (or errors) are then added up and divided by the sum of the observed gradients, thus giving the verification score. This system was applied to two 24-hour prognoses for each day, first using the basic 50% advection of the 700-mb winds, and then applying the adjustments given in Table 3. The scores are presented in Table 4.

Table 4.

Thickness Prognosis Verification Scores

(November 1956)

Date	3	12	13	14	15	16	17	Ave.
Using 50%	0.71	0.52	0.79	0.61	0.57	0.64	1.03	0.70
Using Table 3	0.61	0.45	0.61	0.42	0.49	0.54	0.60	.53

The application of Table 3 resulted in an average improvement of 0.17 in the verification score. The greatest improvement occurred on

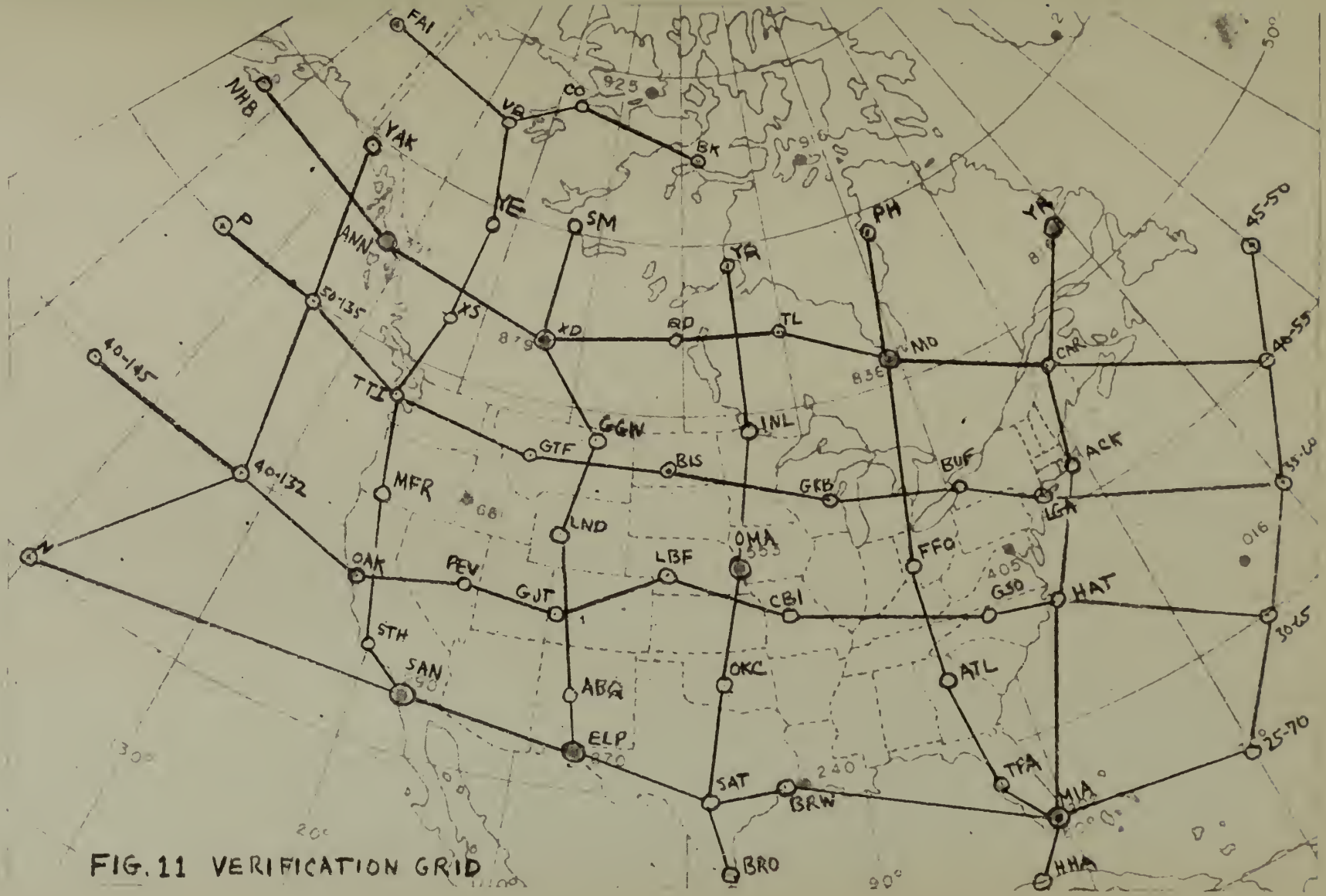


FIG. 11 VERIFICATION GRID

the last of the series, November 16-17, where the verification score using Table 3 was 0.60 as against 1.03 for the unmodified 50% advection. In this last period, the major source of error lay in the vigorous storm development which took place over the eastern United States and Canada. Here, using an unmodified 50% advection resulted in excessive gradients of thickness, and thermal patterns so distorted that some of the forecast gradients were not only greater in magnitude but opposite in direction to the actual gradients. Since there were active areas of strong subsidence upstream, and strong vertical ascent over and downstream from the 700-mb center, application of Table 3 resulted in a more reasonable pattern and a much improved score.

Another source of major error lay in applying the adjustments in Table 3 over the Rocky Mountain and Plateau regions where the original research was not conducted. In cases of warm advection over and immediately to the lee of the Rocky Mountains vertical motions were very weak in the cases studied, hence the adjustments according to Table 3 were slight. However, the warm advection proceeded at a rate considerably in excess of 50% of the 700-mb flow. This was probably the result of (a) the thickness layer over the high terrain, (b) downslope warming which may have not been sufficiently reflected in subsidence at 500 mbs., and (c) non-adiabatic effects such as radiation, etc. Errors elsewhere could of course be attributed in part to inaccuracies in the basic analyses, the assumptions in computing the vertical velocity field, and errors in the application of the method.

5. Conclusion.

From the results obtained from this investigation it appears that further research is definitely necessary before outstanding improvements in the accuracy of prognosticating thickness patterns can be achieved. Although a definite functional relationship exists between vertical motions and the rate of advection of thickness patterns as established both by theory and observation, the other processes should not be neglected. The non-adiabatic contribution should be the subject of further investigation with the goal of refining the prognostic procedure. It is suggested that the movement of thickness patterns over ocean areas be analyzed with respect to sea-surface temperatures and attempts made to establish correlations between the two variables. Such an undertaking should be feasible, since sea-surface isotherms are relatively constant at least over a season. Studies of radiation effects may prove fruitful but pertinent observations on a synoptic basis are not available.

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